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DRYING PROPERTIES OF SOUTH URAL KAOLINS AND KAOLIN-BASED PORCELAIN MIXTURES

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The drying properties of South Ural kaolins and the molding properties of kaolin-based porcelain mixtures are investigated. Practical recommendations are issued.

The present experimental study concentrated on clarifying the drying properties of Ural kaolins and porcelain mixtures based on them, compared with the Prosyanovskoe kaolin and the porcelain mixture based on the latter. As the degree of dispersion of a material has a significant effect on its behavior in drying, the study took into account the data on the sieve analysis and methylene blue absorption of kaolin from the Zhuravlinyi Log, Prosyanovskoe, Kyshtymskoe, and Eleninskoe deposits (Table 1).

The bending strength and the modulus of elasticity of kaolins were studied in drying for different moisture levels. The other investigated parameters were critical moisture, shrinkage, the linear shrinkage coefficient, and the moisture gradient of kaolins and experimental mixtures in drying. Since defects of articles most frequently arise in shrinking of materials, the samples of materials for determining the comparative moisture gradient were taken in the regular drying period. In addition to this, porcelain-mixture samples were taken in the initial drying period after removing the first 1.5 – 2.0% moisture. As for the moisture gradient, in order to obtain more clear data, this parameter was measured in conveying a directed air stream to the sample surface at a high speed equal to 10 m/sec.

Samples 45 mm in diameter and 30 mm high were insulated from moisture transfer from one end and from the lateral side. The cylinders were placed vertically on the insulated end surface, while the other end surface was subjected to the action of the directed air flow. After a certain drying period, the sample was released from the insulation and cut into segments. The selected samples were dried to a constant weight at a temperature of 110°C.

Mixture samples of different compositions were heated under the same parameters. A series of porcelain mixtures was prepared to clarify the effect of the content of Kyshtymskoe and Zhuravlinyi Log kaolin on the formation of defects in porcelain articles.

According to the sieve analysis data (Table 1), the Ural kaolins (Kyshtymskoe, Zhuravlinyi Log, and Eleninskoe) contain significantly more coarse fractions than Prosyanovskoe kaolin does. This analysis does not represent the size distribution of particles in the fraction below 1 μm. However, the drying properties of materials also depend on the amount of finest particles in them, which can be characterized by their specific surface area.

The analysis of methylene blue absorption in kaolins established that the specific surface area of particles in Kyshtymskoe and Zhuravlinyi Log kaolin is higher than in Prosyanovskoe kaolin (the respective absorption is 34 mg/g in the first case, 29 mg/g in the second case, and 19 mg/g in the third case; the same parameter for Eleninskoe kaolin is 13 mg/g). As Kyshtymskoe and Zhuravlinyi Log kaolins also contain up to 5% hydromica, it can be supposed that their specific surface area is partly enhanced by the presence of hydromica.

TABLE 1

Kaolin	Fraction content, %, of size, mm*				
	0.05	0.05 – 0.01	0.01 – 0.005	0.005 – 0.001	0.001
Kyshtymskoe	5.43	19.96	15.53	28.97	35.11
Zhuravlinyi Log	18.80	15.40	17.10	29.30	49.50
Eleninskoe	10.59	34.69	16.07	21.66	16.99
Prosyanovskoe	1.57	13.52	5.61	27.24	42.06

* The dispersing medium was sodium pyrophosphate.

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Thus, compared to the Prosyanovskoe kaolin, Zhuravlinyi Log and Kyshtymskoe kaolin along with a higher content of coarse fractions (from 0.05 or more to 0.005 mm) also have a higher content of the finest particles.

Table 2 indicates the ceramic properties of the considered kaolins and experimental porcelain mixtures.

Several important conclusions can be derived from the obtained results.

Thus, Kyshtymskoe and Zhuravlinyi Log kaolins have a higher molding moisture, shrinkage, linear shrinkage coefficient, and moisture gradient in the drying parameters than Prosyanovskoe kaolin does (Table 3).

The air-dried samples and the samples of Kyshtymskoe and Zhuravlinyi Log kaolin dried at 110°C have significantly higher mechanical strength than Prosyanovski kaolin, but lower strength in shrinking.

The modification of the elasticity modulus in drying has approximately the same nature as the modification of mechanical strength, i.e., the elasticity modulus of Kyshtymskoe and Zhuravlinyi Log kaolin in the elevated moisture state is lower than that of Prosyanovskoe; then it gradually increases, and in the end of drying its value becomes significantly higher.

It can be assumed that the combination of significant amounts of coarse particles and the finest particles is manifested in different ways at different periods of drying.

With an elevated shrinkage coefficient characterizing the intensity of shrinkage, the particle migration during the regular drying period proceeds faster than during slow shrinkage, and the shrinkage of particles is random. Consequently, local heterogeneities in moisture may be formed, which may disturb the mixture coherence. This is presumably manifested in a decreased mechanical strength of the material in drying.

The increased moisture gradients observed in drying of the Kyshtymskoe and Zhuravlinyi Log kaolins points to significant stresses arising in the samples. Together with the low strength of the material in drying, this is indicative of an increased propensity to crack formation.

As bentonite and Veselovskoe clay are more disperse than kaolin, the critical moisture of the porcelain mixtures is lower than that of kaolins. Among the three mixtures considered, mixture 1 has the highest molding and critical moisture, shrinkage, linear shrinkage coefficient, and moisture gradient. Owing to its high critical moisture, the drying period, which is dangerous with respect to defect formation, ends in this mixture sooner than in the other samples. On reaching the level of moisture when shrinkage of the material stops, the moisture-removal process can be significantly intensified. However, the rest of the drying properties show that the mixture with the highest amount of Kyshtymskoe kaolin in combination with bentonite has a greater propensity for defect formation than the other two mixtures.

The use of bentonite additionally increases the molding moisture and the shrinkage of the mixture, which has an unfavorable effect on increasing the drying sensitivity in the mixture. The introduction of a great quantity of Kyshtymskoe kaolin leads to an abrupt increase in the mechanical strength of this mixture in the dry state. However, one can assume that the mechanical strength of this mixture in shrinking, as in kaolin, may be lower than that of the mixture with Prosyanovskoe kaolin.

Mixture 2 in drying behaves in many ways similarly to mixture 1, and yet it is less sensitive to drying and less inclined to the formation of defects in drying.

Mixture 3 has the lowest molding moisture and air-shrinkage parameters. Its parameters of critical moisture, linear shrinkage coefficient, and moisture gradient take an intermediate position.

It is established that the difference in moisture between the evaporation surface and the inner layers of the sample in the initial drying period is significantly greater than in the period of a constant rate of moisture removal. This indicates that heating at the start of drying can be lighter than in the period of a constant rate of moisture removal, especially in mixtures prone to cracking.

The experiments performed on the samples molded as shallow dishes 175 mm in diameter demonstrated that in mixtures with Kyshtymskoe kaolin and bentonite, cracks arise immediately after molding in dry molds (made of Permskoe gypsum).

TABLE 2

Kaolin and experimental mixture	Molding moisture, %		Air shrinkage, %	Bending strength of samples, MPa	
	absolute	relative		air-dried	dried at 110°C
Kyshtymskoe	49.8	33.2	6.2	3.1 – 4.4	6.2 – 7.4
Zhuravlinyi Log	40.1	28.9	6.1	5.5 – 5.9	6.9 – 7.6
Prosyanovskoe	40.8	29.0	4.0	1.2	1.6
Mixture 1	33.6	25.1	5.0	3.4	5.2
Mixture 2	32.0	24.2	4.6	4.6	5.1
Mixture 3	30.4	23.3	3.8	3.8	4.1
Mixture 4	30.9	23.6	4.6	2.6	3.8
Mixture 5	32.1	24.3	4.2	4.3	4.7
Mixture 6	32.2	24.4	5.0	3.9	4.7
Mixture 7	32.0	24.2	4.7	4.2	5.4
Industrial mixture	32.0	23.3	4.2	3.9	4.4

TABLE 3

Kaolin and experimental mixture	Critical moisture, %		Absolute molding moisture, %	Linear shrinkage coefficient	Bending strength of moist samples, MPa	
	absolute	relative			of moisture 29%	of moisture 31%
Kyshtymskoe	25.8	20.50	23.80	0.00385	1.62	0.90
Zhuravlinyi Log	25.9	20.70	24.03	0.00392	1.75	1.63
Prosyanovskoe	24.6	19.70	23.55	0.00354	1.68	1.60
Mixture 1	21.0	17.30	–	0.00378	–	–
Mixture 3	18.8	15.85	–	0.00361	–	–
Mixture 4	17.8	15.10	–	0.00349	–	–

When molding dishes from mixtures 1 and 2 containing 4% bentonite each and 39% Kyshtymskoe or Zhuravlinyi Log kaolin, cracks were registered in the articles molded in all molds. The articles made of mixture 4 (4% bentonite and 39% Prosyanovskoe kaolin) and mixtures 3 and 5 (11% Veselovskoe clay and 33% Kyshtymskoe or Zhuravlinyi Log kaolin) had no cracks after molding.

A decrease in the bentonite content from 4 to 3% made no difference in crack initiation after molding. The replacement of 10% Kyshtymskoe kaolin in mixtures 1 and 2 with 10% Eleninskoe kaolin (mixtures 6 and 7) improved to some extent the resistance of the dishes to cracking.

Thus, the inclination of mixtures to cracking in the initial period of moisture removal can be ranked as follows: mixtures 3 – 5 are the least inclined to cracking after molding, next follow mixtures 6 and 7, and finally, mixtures 1 and 2.

The increased sensitivity to moisture removal in the mixtures containing great quantities of Kyshtymskoe and Zhuravlinyi Log kaolin combined with bentonite is related to the elevated molding moisture of these mixtures and molded dishes, as well as the increased moisture transfer to the gypsum mold.

The experiments performed indicated that the mixtures containing a great amount of Kyshtymskoe and Zhuravlinyi Log kaolin in combination with bentonite are especially sensitive to molding. The stresses arising in molding are manifested in drying. In order to decrease the mixture sensitivity to molding and drying, one should introduce up to 12% Veselovskoe clay instead of bentonite and kaolin, as well as use the low-strength variety of Kyshtymskoe or Eleninskoe kaolin.

It is established that porcelain mixtures containing Kyshtymskoe and Zhuravlinyi Log kaolin and bentonite according to their drying properties can be used in production of household porcelain. The presence of the specified materials in the mixtures increases to some extent their sensitivity to molding and drying compared to the mixtures based on Prosyanovskoe kaolin.

In order to decrease the cracking propensity of the mixtures cracking in drying, it is expedient to use gypsum molds made of high-strength Permskii gypsum, which have to be chilled and moistened before molding, and also reduce by several percent the content of bentonite and kaolin in the porcelain mixture.